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Chemical characterization of biomass burning deposits from cooking stoves in Bangladesh

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ABSTRACT

Biomass burning smoke deposits were characterized from cooking stoves in Brahmondi, Narsingdi, Bangladesh. Arjun, bamboo, coconut, madhabilata, mahogany, mango, rice husk coil, plum and mixed dried leaves were used as biomasses. Smoke deposits were collected from the ceiling (above the stove) of the kitchen on aluminum foil. Deposits samples were analyzed with X-ray fluorescence (XRF) spectroscopy for trace elements determination. UV–visible spectrophotometer was used for ions analysis. The surface morphology of the smoke deposits was studied with scanning electron microscope (SEM). Elevated concentrations of the trace elements were observed, especially for toxic metals (Pb, Co, Cu). The highest concentration of lead was observed in rice husk coil among the determined biomasses followed by mahogany and arjun, whereas the lowest concentration was observed in bamboo. Potassium has the highest concentration among the determined trace elements followed by calcium, iron and titanium. Trace elements such as potassium, calcium, iron showed significant variation among different biomass burning smoke deposits. The average concentrations of sulfate, nitrate, and phosphate were 38.0, 0.60, 0.73 mg kg^{-1}, respectively. The surface morphology was almost similar for these biomass burning deposit samples. The Southeast Asian biomass burning smoke deposits had distinct behavior from European and USA wood fuels combustion.

1. Introduction

Biomass burning emissions are considered to be a significant source for public health hazard and also have a significant impact on climate change [1]. Biomass burning either in open or poorly ventilated stoves emits hundreds of health damaging pollutants and causing acute respiratory infections, chronic obstructive pulmonary disease, asthma, nasopharyngeal and laryngeal cancers, tuberculosis, and diseases of the eye [2]. Pollution from the household burning of the biomasses resulted in more than 1.6 million deaths and nearly 3% of the global burden of the diseases in 2000 [3,4]. Biomass burning emission has significant contribution to the global source of particulate matters and gaseous pollutants [1,2,5]. They are also influencing the chemical composition [6] and properties of the atmosphere [7,8]. About 45% of the global emission of black carbon (BC) is from biomass burning. BC is highly efficient in absorbing solar radiation [7,8]. Major sources of the particulate matters in the atmosphere are from biomass burning throughout the Globe, due to the widespread uses of biomass as fuel for cooking foods and heating spaces [9]. Numerous studies have carried out in North America and Europe for the

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characterization of biomass and fossil fuel burning smoke emissions [10–12]. Whereas, very limited information is available for biomass burning smoke deposition in Southeast Asian region [13–19]. Southeast Asian biomass burning emissions have different chemical properties due to the use of single pod cooking stoves (made of mud) [15]. Biomass burn rates (mass of fuel burned per hour, kg h^{-1}) have also significant influence on aerosol chemical composition. Single pod cooking stoves are producing more carbonaceous species than any other types of biomass combustion. Therefore, biofuels burning are consequently estimated to be the largest contributors to the ambient elemental carbon in Southeast Asia [16].

Bangladesh is a rapidly growing Southeast Asian country. About 80% people of the country are still living in the rural areas. Almost 70% of them are using varieties of biomasses including rice husk, straw, cow dung, jute stick, bagasse, bamboo, dry leaves, and woods as main fuels for cooking foods [17]. Not many studies were done for chemical characterization of biomass burning deposition/emission in Bangladesh [19–22]. Characterization of the organic aerosol emissions including total organic and elemental carbon, sulfate, nitrate, ammonium and chloride ions from combustion of coconut leaves, rice straw, jackfruit branches, dried cow dung were done in Bangladesh [14]. Bulk elements such as potassium and sodium did not have any significant differences among biomass samples, but organic compound fingerprints of the particulate matter have shown distinct behavior from one another, and also distinct from North American wood fuels. Lead, iron, cadmium, calcium, potassium and magnesium were identified from two different types of biomass samples [19]. The emission of lead, iron, cadmium, calcium, potassium and magnesium were much higher in mixed ash compared than that of the rich husk coil [19]. Airborne particulate matter samples were collected during combustion of biomass fuels (wood, cow dung, and crop wastes) from cooking and living spaces at rural homes in Bangladesh to investigate the impact of fuel use, kitchen configurations, and ventilation on indoor air quality, and also to apportion the source contributions of the trace metals and BC concentrations [20]. Particulate matters deposition varied significantly depending on the position of kitchen, fuel use, and also ventilation rates [20].

In this paper, we are focusing on the chemical characterization of biomass burning smoke deposition from cooking stoves at the rural areas in Brahmondi, Narsingdi, Bangladesh. Smoke deposit samples were collected on the aluminum foils from the ceiling (above the cooking stoves) in the kitchen and subsequently analyzed for trace elements with XRF method and ions with UV–visible spectrophotometer.

2. Methods and experimentals

2.1. Sampling location – Brahmondi, Narsingdi, Bangladesh

Bangladesh is situated in the eastern part of south Asia. It is surrounded by India on the west, north and the northeast, Myanmar on the southeast, and the Bay of Bengal on the south. Map of the sampling location (Brahmondi, Narsingdi) has given in elsewhere [19]. Narsingdi is a district of Dhaka division and about 52 km away from the capital Dhaka. Narsingdi Sadar (Town) consists of nine wards and thirty three mahallas. The area of Narsingdi town is 14.76 km^2 with a population of 42023; density of population km^{-2} is 2847. Literacy rate among the town people is about 52%. The Narsingdi district consists of six upazilas, and three municipalities [19]. The sampling location, Brahmondi is a small village, which is few kilometers from Narsingdi district town. Brahmondi is considered as a rural area in Bangladesh. The main activities of the people of Brahmondi village are agriculture and small industry. Socio economic situation of the people of the sampling locations is not good. Most of the people are working as a day labor. They are cooking meals normally two times daily at the cooking stoves by using varieties of biomasses at different types of kitchens as well as stoves.

2.2. Types of the kitchen and stoves

2.2.1. Types of the kitchen

There are many varieties of the kitchens. They are not well decorated and even not well ventilated in Brahmondi, Narsingdi, Bangladesh. Most of them are made of straw and bamboo. Some kitchens have no window and some have only one door. Some kitchens have fully opened and have only straw made roof. Some kitchens are no door, and three sides are fully open. Other kinds of kitchens are fully surrounded by bamboo and a roof made of tin.

2.2.2. Types of stoves

Deposition of biomass burning is extremely dependent on types of biomass, cooking stoves configuration, and also on the ventilation of the kitchen [20]. The people in Brahmondi, Narsingdi, Bangladesh are using different types of cooking stoves. Most of the cooking stoves (Fig. 1) are made of mud (local name is "Chula"). Some stoves are permanent, and some are mobile, and some are box types. These cooking stoves have one, two or multi channels for putting biomass inside the stoves. In this study, we were using single channel cooking stoves for biomass feeding with poor ventilation at the kitchen having three sides closed and one side open.

2.3. Smoke deposits samples collection

Smoke deposits samples were collected from the ceiling (above the stove) in the kitchen after deposition of biomass burning particles from cooking stoves from January to March in the rural Brahmondi, Narsingdi, Bangladesh. Branches of arjun (*terminalia arjuna*) trees, bamboo (*bambuseae*), branches of coconut (*cocos nucifera*) trees, madhabilata (*quisqualis indica*), branches of mahogany (*swietenia macrophylla*) trees, branches and leaves of mango (*mangifera indica*) trees, plum (*prunus domestica*) trees, rice (*oryza sativa*) husk coil, and varieties of dried leaves (Table 1) were used as biomasses. Ages of the biomasses were varied from one year to twenty five years (Table 1). Coconut has the highest (25 years) while bamboo has the lowest (2 years) age. Through, the rice husk coil and mixed biomass were one and two years, respectively. Biomass burning experiments were started after cleaning the inside surface of the kitchen's roof. A picture of the typical kitchen in a rural house has given elsewhere [19]. About 10 kg of biomass was burned at each cooking stoves daily. After collection, the samples (picture has given in Ref. [19]) were wrapped with aluminum foil and transported to the Department of

Fig. 1 – Typical cooking stoves used for the biomass burning smoke deposition at the rural areas in Brahmondi, Narsingdi, Bangladesh.

Chemistry, University of Dhaka. The samples were stored in the refrigerator to avoid contamination and also kept them free from any kind of moisture absorption until analysis.

2.4. *Meteorology of Narsingdi, Bangladesh*

The climate of Bangladesh is characterized by high temperatures, excessive humidity and distinctly marked seasonal variation of precipitation. Meteorologically, the year of Bangladesh can be divided into four seasons, pre-monsoon (March–May), monsoon (June–September), post monsoon (October–November) and winter (December–February). Average meteorological conditions in Dhaka, Bangladesh at different seasons were also given elsewhere [23,24]. The average temperature variation was 9 °C–32 °C during the period from January to March. Only few precipitation events were observed during the Month of March, though precipitation had no effect on the smoke deposition as well as sample collection.

2.5. *Analytical methods*

2.5.1. *X-ray fluorescence (XRF) spectroscopy*

An x-ray fluorescence spectroscopy (model SL 80175, serial no.1199902) method was used to analyse smoke deposits for the determination of K, Ca, Ti, Fe, Mn, Zn, Br, Rb, Sr, Y, Zr, and Pb concentrations. Details of the methods and principles were described in somewhere else [25–27]. This XRF method has already validated with a quality assurance test for trace element analysis in marine sediment among 103 laboratories from 47 countries all over the World [25]. The excitation source used for energy dispersive x-ray fluorescence (EDXRF) spectrometer was a 25 mCi (0.37GBq) Cd-109 radioisotope (emitting Ag–K X-rays). The characteristic X-rays along with scattered excitation radiation were simultaneously detected with a 30 mm^2 ORTEC Si(Li)diode with a 6.0 mm active diameter and a 5.1 mm sensible thickness. After irradiation of the samples, the x-ray spectra were collected with a multichannel analyzer and interpreted with the software of *Analysis of X-Ray Spectra by Iterative Least Squares Fitting (AXIL)* [26]. To determine the sensitivity factor of each element and also to compensate the matrix effect, calibration was carried out with five independent measurements of Orchard leaves standard (NIST SRM 1571). The sensitivity of each element was calculated form the average peak area of five independent measurements of the standard. The calibration curve was constructed by plotting the sensitivity of the standard elements as a function of their atomic numbers (Fig. 2). The concentration of each element was calculated from the respective calibration factor from the sensitivities of the standard element as a function of atomic number. Quality assurance (QA) and quality control (QC) in the measurement process was ensured by analyzing Pine Needles standard sample. Comparison between certified and experimental values of trace and minor elements concentration in Pine Needles has given in Fig. 3. The minimum detection limit (MDL) of the method was determined with IAEA-SL3 standard (marine sediment) for 3000 s irradiation time. Form the consideration of statistical uncertainty associated with x-ray counting, the MDL is defined as the amount of an element in mg kg^{-1} present in the sample, which will yield X-ray intensity equal to 3σ of the background under the photo-peak. The limit of detection (LOD) for the determined trace elements has given in Table 2.

Table 1 – The scientific names and ages of the biomasses were burning at the cooking stoves to collect smoke deposits in the rural area, Brahmondi, Narsingdi, Bangladesh.

Serial no.	Common name	Scientific name	Ages (years)
1.	Arjun	*Terminalia arjuna*	23
2.	Bamboo	*Bambuseae*	02
3.	Coconut	*Cocos nucifera*	25
4.	Madhabilata	*Quisqualis indica*	08
5.	Mahogany	*Swietenia macrophylla*	05
6.	Mango	*Mangifera indica*	15
7.	Rice husk coil	*Oryza sativa*	01
8.	Plum	*Prunus domestica*	14
9.	Various dry leaves	–	1–2

2.5.2. *Scanning electron microscope (SEM)*

A scanning electron microscope (SEM), model S-3400 N, Hitachi, Japan was used to characterize the surface morphology of the smoke deposit samples after burning of biomasses (rice husk coil, bamboo and mahogany) at the cooking stoves. SEM

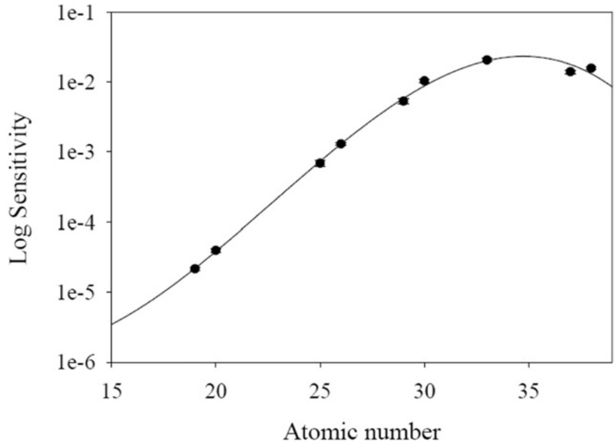


Fig. 2 – X-ray yield curve for calibration of the elemental concentration constructed from Orchard leaves matrix (NIST SRM 1571).

took less than 100 s to exchange a specimen and 6 min to reach ready status from the cold start. The required power supply was only 2.0kVA.

2.5.3. *UV–visible spectrophotometer*

An UV–visible spectrophotometer (model UV-160A), Shimadzu, Japan was used to determine the ion concentrations (sulfate, phosphate, and nitrate) from smoke deposit samples. The details of the determination methods for sulfate, phosphate, and nitrate analysis were given in the earlier publication [28].

Sulfate: 10 ml sample solution was taken in a 25 ml volumetric flask and added 5 ml of glycerin solution (1:1) and 2.5 ml of NaCl solution and upon stirring add 0.15 g of $BaCl_2 \cdot 2H_2O$ crystals. The volumetric flask filled up to the mark with de-ionized, and measured the absorbance at 380 nm with UV–visible spectrophotometer using a reagent blank. The concentration was calculated from the calibration curve of five standards Na_2SO_4 solutions of different concentrations.

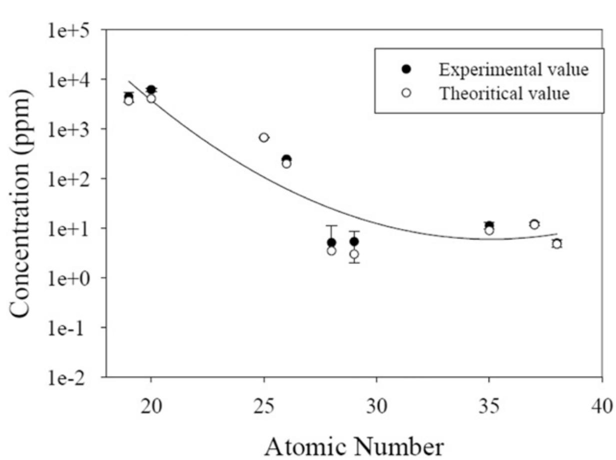


Fig. 3 – Comparison between certified and experimental values of trace elements concentration (mg kg^{-1}) in pine needles.

Table 2 – The minimum detection limit for the elements determined with X-ray fluorescence (XRF) spectroscopy.

Elements	K	Ca	Ti	Fe	Mn	Zn	Br	Rb	Sr	Y	Zr	Pb
mg kg^{-1}	1221	655	196	15.8	27.1	2.29	0.92	1.31	1.88	1.80	1.86	9.06

Phosphate: 17.5 ml sample was taken in 25 ml volumetric flask, added 20.0 ml metavanadate solution and filled the flask up to the mark with de-ionized water. After 20 min, the absorbance of the solution was measured at 358 nm using a reagent blank. The concentration was calculated from the calibration curve with five known standard concentrations of KH_2PO_4 solution.

Nitrate: 2.5 ml sample was taken in a 25 ml volumetric flask, added 0.10 ml brucine reagent and 10.0 ml of concentrated H_2SO_4 carefully in a cooling bath. The flask was then allowed to stand for about 10 min until the color of the brucine reagent changed from reddish purple to yellow. The volumetric flask then made up to the mark with de-ionized water and mixed cautiously. The flask was then cooled at room temperature, and the absorbance of the sample solution was measured at 410 nm using a reagent blank. The concentration was calculated from the calibration curve with five known concentrations of standard nitrate solution.

3. Results and discussion

3.1. *Overview of the results*

The study involves the chemical characterization of biomass burning smoke deposits from cooking stoves (made of mud) at the rural areas in Brahmondi, Narsingdi, Bangladesh. Arjun, bamboo, coconut, madhabilata, mahogany, mango, mixture of varieties of leaves and trees, rice husk coil and plum were used as biomasses. The smoke deposits were collected from ceiling above the cooking stoves in the kitchen on the aluminum foil and brought them to the Analytical Chemistry Laboratory, Inorganic and Environmental Section, Dhaka University. Sieve analysis showed that smoke deposits for all biomasses were below 140 μm in size. Potassium, calcium, titanium, manganese, iron, cobalt, copper, zinc, bromine, rubidium, strontium, yttrium, zirconium, niobium, molybdenum, and lead were determined with X-ray fluorescence (XRF) method (Table 3). Sulfate, nitrate, and phosphate were determined with UV–visible spectrophotometer. The trace element concentrations at these nine biomass burning deposits were different. Mango has the highest of the sum of trace metals concentration, whereas the bamboo has the lowest. If we look individual trace elements, then the scenarios are different, e.g., copper concentration was highest in mango, whereas the lowest was in bamboo (Table 3). In case of cobalt, the highest concentration is in mango, whereas the lowest concentration is in plum – Table 3. The content of the elements and also the percentage composition of the elements are different between these biomasses. E.g., Aluminum and sulfur are present in bamboo, but they are below detection limit in rice husk coil. The detail of the results has given in Section 3.3.

Table 3 – The concentration of trace elements and ions in the biomass burning smoke deposits from cooking stoves in Brahmondi, Narsingdi, Bangladesh. Trace elements were determined with X-ray fluorescence (XRF) and ions were determined with UV–visible spectrophotometer. All the units are in mg kg^{-1}.

Elements	Arjun	Bamboo	Coconut	Rice husk coil	Madhabilata	Mahogany	Mango	Mixed ash	Plum	Average
K	12983	38169	25838	15772	20030	11927	7294	14653	29985	19627
Ca	6664	4189	6995	5008	7000	5991	10059	4009	7846	6418
Fe	4147	2624	3356	3898	3805	4247	47.7	4555	2621	3256
Ti	717	559	600	621	685	808	706	659	636	665
Mn	76.9	72.6	98.8	108	80.2	99.7	78.44	171	93.6	98.0
Co	21.4	24.4	31.5	30.9	28.7	37.3	46.3	40.0	18.0	31.0
Cu	19.1	9.94	13.2	17.8	11.2	20.4	219.0	27.6	12.3	39.0
Zn	149	77.2	107	172	217	175	6.22	72.9	159	126
Br	20.2	47.7	39.5	27.0	21.6	15.5	19.1	37.1	44.4	30.0
Rb	26.6	94.0	71.9	51.8	41.8	31.6	20.6	89.5	45.8	52.0
Sr	48.7	51.1	60.4	51.0	53.6	46.3	56.6	57.2	60.7	54.0
Y	10.7	11.5	9.9	14.3	9.7	14.2	11.6	16.0	7.8	12.0
Zr	147	273	175	166	187	214	151	245	130	187
Nb	27.6	30.6	26.1	25.5	32.4	23.8	17.6	36.6	16.6	26.0
Mo	32.5	56.1	10.3	13.5	43.0	2.10	54.2	35.9	17.1	29.0
Pb	314	50.8	210	506	177	458	217	191	231	262
SO_4^{2-}	55.3	40.3	19.9	136.3	15.3	17.3	20.3	17.8	26.8	38.0
PO_4^{3-}	0.79	0.99	0.51	0.25	0.50	0.95	0.48	0.35	0.52	0.60
NO_3^{2-}	BDL	BDL	1.00	0.33	4.73	BDL	BDL	BDL	0.47	0.73

3.2. *Physical characteristics of the samples*

The physical appearances of the collected biomass burning smoke deposit samples from cooking stoves were flaky (not crystalline) powder, black in color, and odorless. They are highly insoluble either in cold or hot water or dilute hydrochloric acid, or nitric acids. They are highly soluble in concentrated sulfuric acid and also soluble in concentrated hydrochloric acid.

3.3. *Trace metals determination with X-ray fluorescence (XRF) spectroscopy*

Potassium, calcium, titanium, manganese, iron, cobalt, copper, zinc, bromine, rubidium, strontium, yttrium, zirconium, niobium, molybdenum, and lead were determined in smoke deposit samples with X-ray fluorescence (XRF) after burning of biomasses (arjun, bamboo, coconut, madhabilata, mahogany, mango, mixed ash, rice husk coil and plum) at cooking stoves in Brahmondi, Narsingdi, Bangladesh. The grand average of K, Ca, Fe, Ti, Mn, Co, Cu, Zn, Br, Rb, Sr, Y, Zr, Nb, Mo, and Pb were 19627, 6418, 3256, 665, 98, 31, 39, 126, 30, 52, 54, 12, 187, 26, 29, and 262 mg kg^{-1}, respectively (Table 3). Many studies have already done for the chemical characterization of biomass burning smoke emission/deposition in the developed countries. Whereas, very limited information was found for the biomass burning smoke deposits from Southeast Asian countries. We have complied data in Table 4 from European, American and Southeast Asian biomass burning smoke emissions along with the current measurements. Due to the scarcity of the data, we are not able to compare our data with other smoke deposition. Still, it would be good to see the differences between smoke depositions versus smoke emissions. This information will help us to understand the occurrences of the trace metal concentrations from biomass burning smoke deposition and emissions. The details of elemental concentration have given at the below.

Potassium (K): K is often used as a marker for the wood smoke. K has the highest concentration among the determined trace elements, which again prevailed that the biomass burning is the largest contributor of K to the atmosphere. The highest concentration of K was observed in bamboo, whereas the lowest concentration was found in mango. K concentration among these nine biomasses were followed the sequences; bamboo > plum > coconut > madhabilata > rice husk > mixed ash > arjun > mahogany > mango. The average K concentration from coniferous and deciduous biomasses combustion in a European location was 13.5 times lower than the total average concentration of nine biomasses in the current study (Table 4). The average K concentration in mango was exactly similar to the olive concentration but about 1.66 and 1.87 times higher than the cork oak and briquettes concentrations, respectively in the fireplace combustion (Table 4).

Calcium (Ca): Ca is an essential element for human health. Ca has the second highest concentration among the determined trace elements in Brahmondi, Narsingdi, Bangladesh. The highest concentration of Ca was observed in mango, which was 1.6 times higher than the total average concentration of nine biomass samples. The lowest concentration of Ca was observed in mixed ash, which was 1.66, 1.04, 1.74, 1.25, 1.75, 1.49, 2.51, 1.96 times lower than arjun, bamboo, coconut, rice husk coil, madhabilata, mahogany, mango, plum, respectively. The overall average of the smoke deposit concentration of Ca in Bangladesh was relatively higher than European, and USA biomass combustion (Table 4). Through Ca does not have harmful effect, but plays a significant role on rain, water as well as soil chemistry for the ion balance. Burning of deciduous biomass at the fireplace also has emitted similar Ca, but coniferous has almost double concentration compare than the overall average in the current study (Table 4).

Iron (Fe): The highest average Fe concentration was observed in mixed ash while the lowest was in mango with the total average of 3256 mg kg^{-1}. Fe has the third highest concentration among the determined trace elements in

Table 4 – Comparison of the elemental concentrations of the biomass burning deposits data with international measurements. All the units are in mg kg^{-1}. ND means not determined.

Elements	Current study	Obernberger et al., 2006 [29]	Schmidl et al., 2008 [30]	Schmidl et al., 2008 [31]	Alves at al. 2011 [32]		Fine et al., 2001 [12]		Sheesley et al., 2003 [16]	McDonald et al., 2010 [33][Hardwood]	
					Fireplace	Woodstove	Hardwoods	Softwoods		Fireplace	Woodstove
K	19627	1450	7525	1740	7764	9462	10707	10810	20106	67.4	15.4
Ca	6418	5183	705	499	318.1	72.3	–	160	–	–	–
Fe	3256	108	–	–	–	440	–	–	0	–	–
Ti	665	–	<1	14	0.33	0.6	–	–	0	–	–
Mn	98	215	<1	156	6.10	21.9	–	–	8.0	–	–
Co	31	–	<21	<30	ND	–	–	–	4.0	–	–
Cu	39	2.3	<1	285	ND	–	–	–	ND	–	–
Zn	126	28.3	199.5	790	57.9	24.7	1807	353	92.0	–	–
Br	30	–	–	–	–	–	50	20	138	–	–
Rb	52	–	–	–	–	–	56.7	50	–	–	–
Sr	54	–	–	–	2.38	2.7	–	–	0.0	–	–
Y	12	–	–	–	–	–	–	–	–	–	–
Zr	187	–	–	–	–	–	–	–	–	–	–
Nb	26	–	–	–	–	–	–	–	–	–	–
Mo	29	–	–	–	–	–	–	–	0.0	–	–
Pb	262	3.5	20	28	8.73	229	85	40	–	–	–
SO_4^{2-}	38	–	2180	1950	–	–	8033	2533	5820	27.5	26.6
PO_4^{3-}	0.6	–	–	–	–	–	–	–	–	–	–
NO_3^{2-}	0.73	–	220	742	–	–	4267	3167	1840	9.94	0.59

Brahmondi, Narsingdi, Bangladesh. The observed concentration in mixed ash was almost 10 times higher than that of mango. Arjun and mahogany have almost similar concentrations for Fe. Rice husk coil and madhabilata also have almost similar concentrations but slightly lower than arjun and mahogany. Plum and bamboo samples also have similar concentrations, but about half of the arjun and mahogany (Table 3) samples. Deciduous combustion at the fireplace had almost similar concentration of mango sample in smoke deposition at the cooking stoves. On the other hand, coniferous emission was about 3.67 times higher than mango. Fe concentration observed from the burning of pine biomass at the woodstove was about 9 times lower than arjun and about 9 times higher than mango (Table 4). Deposits from biomass burning at the cooking stoves are truly dependent on the types of biomasses used as fuels.

Titanium (Ti): The highest average concentration of Ti was observed in mahogany branches, whereas the lowest concentration was in bamboo samples. The total average concentration of these nine biomass samples was 665 mg kg^{-1}, which was unusually high concentration for Ti. The measured value of Ti from the combustion of biomasses at the fireplace was 0.464 mg kg^{-1} for golden wattle, 0.203 mg kg^{-1} for olive and 0.56 mg kg^{-1} for Briquettes (Table 4). The observed concentration of Ti was less than 20 mg kg^{-1} in coniferous and deciduous wood burning without bark. The variation of Ti concentrations among nine biomass samples at Brahmondi, Bangladesh was not significant. The differences between the highest and lowest values were only 30%.

Manganese (Mn): Mn has much lower concentration compare to K, Ca, Fe and Ti, but much higher concentration compared to Co, Cu, Y, Nb, and Mo in Brahmondi, Narsingdi, Bangladesh. The total average concentration of Mn in nine biomass samples was 98.0 mg kg^{-1}, which was about 14.8 times higher than the average of eight biomass burning combustions at the fireplace in Europe, and also 3.1 and 1.3 times lower than the average of coniferous and deciduous wood burning combustions, respectively. The highest concentration of Mn was observed at the mixture of various dried leaves, and the lowest value was observed in bamboo burning smoke deposits. The coniferous wood with bark produced 500 mg kg^{-1}, and the deciduous wood without bark produced only 83 mg kg^{-1} of Mn in Europe (Table 4).

Cobalt (Co): The total average concentration of Co in nine biomass samples was 31.0 mg kg^{-1}. The highest value was in mango, and the lowest value was in plum samples. Open burning of dry leaves in Europe showed about 30 mg kg^{-1} Co in particulate matter emissions (PM_{10}) (Table 4).

Copper (Cu): The average concentration of Cu among nine biomass samples was 39.0 mg kg^{-1}. In European open burning deposits of dry leaves showed about 285 mg kg^{-1} of Cu in particulate matters (PM_{10}). The average copper concentration of two biomasses (coniferous and deciduous) in Europe was about 17 times lower than the average of nine biomass burning deposits in the current study. The variations of the Cu concentration among nine biomass samples were relatively high – the average Cu concentration in mango was 22 times higher than bamboo, 20 times higher than madhabilata, 17 times higher than coconut burning smoke deposits (Table 4).

Zinc (Zn): Zn is an essential element for the plant growth. Therefore, elevated concentration of Zn is to be expected in the biomass burning deposits. Relatively higher concentrations were observed in all the biomasses except mango. The highest average concentration of Zn was observed in madhabilata, and the lowest concentration was in mango. The grand average concentration of Zn was about 4 times higher than the average of two biomass (coniferous and deciduous) combustion samples. About 4 times higher Zn concentration was also observed in wood combustion at the particulate matters in Europe. The average Zn concentrations were 390, 120, 4910, 210, 120, and 730 mg kg^{-1} in red maple, northern red oak, paper birch, eastern white pine, eastern hemlock and balsam fir, respectively (Table 4). However, the overall Zn emission in European and US biomass burning emission seem much higher than the current smoke deposits.

Bromine (Br): The grand average value of Br in nine biomass burning smoke deposit samples was 30.0 mg kg^{-1} with the highest value was in bamboo and the lowest was in mahogany. The average Br concentration in three hardwoods in northeaster USA at the fireplace was 50 mg kg^{-1}. The paper birch has almost double Br concentration compare than that of the total average in Brahmondi, Narsingdi, Bangladesh (Table 4).

Rubidium (Rb): The grand average Rb concentration in nine biomass samples was 52.0 mg kg^{-1}, which was almost similar to the average of six Northeastern wood species combustion in USA. The highest value of Rb was in bamboo, and the lowest was in mango smoke deposit samples. The average Rb concentrations were observed 60, 50, 60, 20, 20, and 80 mg kg^{-1} in red maple, northern red oak, paper birch, eastern white pine, eastern hemlock and balsam fire, respectively at the fireplace combustion in Northeastern USA with a grand average of 48.3 mg kg^{-1} (Table 4).

Strontium (Sr): The average concentrations of Sr and Rb were almost similar at Brahmondi, Narsingdi, Bangladesh. The average concentration of Sr was 54.0 mg kg^{-1} with the highest average in plum and the lowest average in mahogany. The average Sr concentration in wood combustion was about 3 times lower than the current grand average value. The average Sr concentration of six European biomass combustion samples at the fireplace was 2.26 mg kg^{-1}, which was about 24 times lower than the total average of biomass burning deposition in Brahmondi, Narsingdi, Bangladesh (Table 4).

Yttrium (Y): The total average concentration of Y in nine biomass burning samples was 12.0 mg kg^{-1}. There was no significant variation for the Y concentration in biomass smoke deposits. The highest concentration was in various dry leaves, but the lowest value was in plum. Unfortunately, there was no other data of Y in Table 4 for the comparison.

Zirconium (Zr): The total average concentration of Zr was 187.0 mg kg^{-1} at the rural areas in Brahmondi, Narsingdi, Bangladesh. The highest Zr concentration was observed in bamboo whereas the lowest concentration was in plum smoke deposits. The Zr concentration in arjun, coconut, rice husk coil, madhabilata, mahogany, mango, mixed ash and plum was about 54, 64, 61, 68, 78, 55, 90 and 48% of the bamboo, respectively (Table 3).

Niobium (Nb): The total average concentration of Nb was 26.0 mg kg^{-1} in nine biomasses. The highest Nb concentration was observed in mixed ash whereas the lowest concentration was in plum (Table 2). The Nb concentration among these nine biomasses follows the sequences, mixed ash > madhabilata > bamboo > arjun > coconut > rice husk coil > mahogany > mango > plum.

Molybdenum (Mo): The highest average concentration of Mo was observed in bamboo, whereas the lowest concentration was in mahogany with the total average of 29.0 mg kg^{-1}. Bamboo and mango have almost similar Mo concentrations, which are about 25 times higher than mahogany, and about 5 times higher than coconut samples.

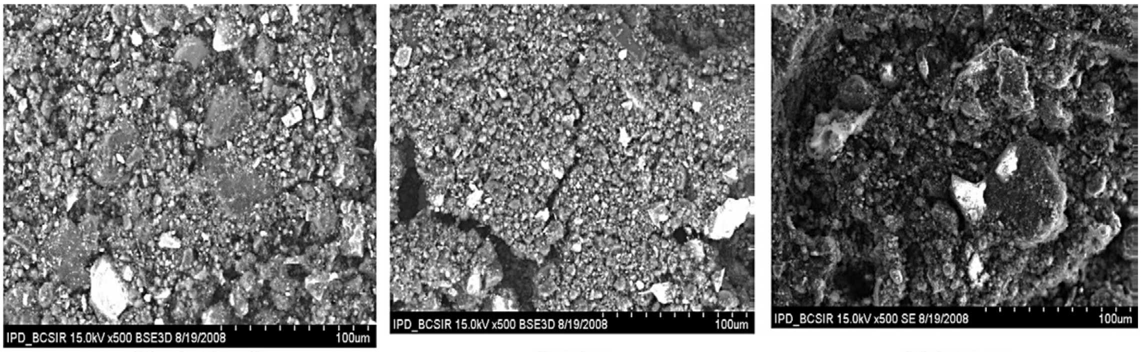
Lead (Pb): The total average Pb concentration was 262 mg kg^{-1} at the rural Brahmondi, Narsingdi, Bangladesh. The highest concentration was observed at rice husk coil, and the lowest was in bamboo. The average concentrations of Pb in arjun, bamboo, coconut, madhabilata, mahogany, mango, mixed ash and plum were 62.1%, 10.0%, 41.5%, 35.0%, 90.5%, 42.9%, 37.7%, 45.7%, and 51.8% of the rice husk coil deposits, respectively. Lead concentrations in these biomass samples were relatively higher with respect to the natural atmospheric lead concentration [23]. The average Pb concentration of nine biomasses was about 75 times higher than the average of two European biomass (coniferous and deciduous) burning combustion (Table 4). We had measured the Pb concentrations in the soil of Brahmondi, Narsingdi at different depths (0, 10–12, and 23–25 cm) to identify the sources of high lead content in Bangladesh. It was observed that Pb concentrations were also high in the soil. 25.4 ± 2.06 mg kg^{-1} Pb was observed at the surface (0 cm), 33.9.4 ± 2.03 mg kg^{-1} Pb was found from surface to 12 cm depths of the soil, and 33.1 ± 2.00 mg kg^{-1} Pb was obtained between 23 and 25 cm depth of soils. However, soil had a significant contribution to the high lead concentration in biomass smoke deposits along with other sources. Lead had the highest average value for the biomass burning deposits in Table 4. The lead value was 75 times higher than the average value of two biomass burning combustions in Austria, 13 times, 9 times and 30 times higher than other three European locations, 3 (hardwoods) and 6.55 (softwood) times higher than the northeastern USA wood burning combustions (Table 4). However, the European woodstove burning emission was comparable to the average Pb value at biomass burning smoke deposits in Narsingdi, Bangladesh.

3.4. *Surface characterization with scanning electron microscope (SEM)*

Scanning electron microscope (SEM) was used to characterize the surface morphology of the smoke deposits samples obtained from biomass burning from cooking stoves in the kitchen at the rural areas in Brahmondi, Narsingdi, Bangladesh. BSE images of the surface of smoke deposit materials after burning of rice husk coil, bamboo, and mahogany have given in Fig. 4. The surface morphology of the smoke deposits was almost similar for these biomasses. The smoke deposits surfaces may contain dust, sulfate, nitrate and also oxides of different metals dominating by carbonaceous species.

3.5. *Ions determination with UV–visible spectrophotometer*

Sulfate (SO_4^{2-}): The total average sulfate concentration in Brahmondi, Narsingdi, Bangladesh was 38.0 mg kg^{-1} with the



Rice husk coil Bamboo Mahogany

Fig. 4 – Scanning electron microscope image (Model S-3400 N, Hitachi) of biomass burning smoke deposits after burning of rice husk coil, bamboo and mahogany at the cooking stoves in Brahmondi, Narsingdi, Bangladesh.

variation between 136.3 (rice husk coil) and 15.3 mg kg^{-1} (madhabilata). Sulfate concentration is particularly important for the ion balance, and also for the precipitation chemistry. A study on selected hardwoods (red maple, northern red oak and paper birch) and softwoods (eastern white pine, eastern hemiock and balsam fir) species in northeastern USA reported abnormally high sulfate concentration at fireplace combustion [10]. The average sulfate concentration in Northeastern USA was about 139 times higher than the current study. The hardwoods species produced about 3 times more sulfate than softwoods (Table 4). The average sulfate concentration was 1950 mg kg^{-1} from a wood combination (70% spruce, 20% beeck and 10% briquettes) in particulate matters (PM) observed in Europe. However, the sulfate concentration in smoke deposits was much lower compared than biomass burning emission in Europe and USA.

Phosphate (PO_4^{3-}): Very low phosphate concentration was observed in Brahmondi, Narsingdi, Bangladesh with an average of 0.60 mg kg^{-1}. The highest average concentration of phosphate was in bamboo and lowest in rice husk coil (Table 3). Bamboo and mahogany had almost similar phosphate concentration. Coconut had similar concentration of madhabilata, and almost half of bamboo and mahogany but about double than the rice husk coil samples.

Nitrate (*currhskip0ptNcurrhskip0pt*O_3^-): The average nitrate concentration (coconut, rice husk coil, madhabilata, and plum) was 0.73 mg kg^{-1}. Arjun, bamboo, mahogany, mango, and mixed ash had the value bellow detection limit (BDL). Relatively low nitrate concentration was observed at biomass burning smoke deposit in Bangladesh compare to the emission of wood combustion in Table 4.

4. Conclusion

This study involves the chemical characterization of smoke deposits of nine biomasses burning from cooking stoves at the rural areas in Brahmondi, Narsingdi, Bangladesh. Biomasses burning smoke deposit samples were collected on the aluminum foil from the ceiling of the kitchen. The surface morphology of the smoke deposits was almost similar. The concentration profile of the smoke deposits was mainly depending on the types of biomasses. Elevated concentrations of the trace metals were observed with XRF measurements. K had the highest concentration, whereas Y had the lowest concentration among the determined trace elements. They followed the sequence as, K > Ca > Fe > Ti > Pb >Zr > Zn > Mn > Sr > Rb > Cu > Co > Mo > Nb > Y. The concentrations of the determined components at these nine different biomass burning smoke deposits was much higher compare to the European and USA biomass burning emissions.

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